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AD A102240

HEADQUARTERS STRATEGIC AIR COMMAND

Directorate of Aircraft Maintenance

Aircraft Engineering Division

Engineering Report No. S-114

A STATEMENT OF WORK FOR AN AERONAUTICAL SYSTEM NUCLEAR HARDNESS PROGRAM

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9 Final rept.

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29 Jun[redacted]981

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Unclassified

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Approved for public release; distribution unlimited.

14 SAC/LGME-ER-S-114

Nuclear Survivability/Vulnerability, Nuclear Hardness Program Plan, Statement of Work, Nuclear Radiation, Aircraft, Lifecycle Survivability, Hardness Assurance.

This report consists of a Nuclear Hardness Statement of Work (SOW) Appendix intended for incorporation into a major system full scale development Statement of Work. This SOW Appendix is unique because its objective is the achievement of hardness at minimum life cycle cost.

Strong emphasis is placed on the initial design phase to eliminate/minimize hardness critical items whose monitoring and control efforts during production and over the operational life of the system result in high life cycle costs. Strong emphasis is also placed on assuring that production systems are hard and

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(Abstract Continued)

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A Statement of Work

for an Aeronautical System

Nuclear Hardness Program

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ABSTRACT

This report consists of a Nuclear Hardness Statement of Work (SOW) Appendix intended for incorporation into a major system full scale development Statement of Work. This SOW Appendix is unique because its objective is the achievement of hardness at minimum life cycle cost.

Strong emphasis is placed on the initial design phase to eliminate/minimize hardness critical items whose monitoring and control efforts during production and over the operational life of the system result in high life cycle costs. Strong emphasis is also placed on assuring that production systems are hard and on maintaining hardness during operational deployment.

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Statement of Work

Appendix ___

Nuclear Hardness

1.0 SCOPE AND OBJECTIVE

1.1 SCOPE. This Appendix establishes the tasks required during full scale development to insure that the system is capable of successfully withstanding exposure to the nuclear environmental levels specified in the system specification and to develop a foundation for efforts to insure that this design hardness is not degraded during production and operational deployment.

1.2 OBJECTIVE: The major objective of this Appendix is the achievement of maintainable hardness at minimum life cycle cost.

2.0 GENERAL CONSIDERATIONS

2.1 To insure that design hardness is achieved, and that hardness is not degraded during production and operational deployment, a complete, integrated lifecycle survivability program must be developed and implemented throughout the entire acquisition process.

2.2 Once a comprehensive set of nuclear criteria have been developed and validated, they are incorporated into the full scale development as design requirements. After this point, changes to those criteria evoke ripple like effects throughout the numerous Air Force/DOD, contractor/subcontractor organizations, and numerous other agencies directly or indirectly involved in the program. Therefore such changes are strongly discouraged and only drastic alterations in the original basis of the criteria would substantiate such change.

2.3 It is the intent of the Air Force that the Nuclear Survivability Program be optimized over the system life. A major feature of such optimization is the delineation of system elements and manufacturing/inspection techniques into hardness critical categories. The most critical categories will be subjected to special emphasis while less critical categories would be afforded only standard program attention. Therefore extra effort to incorporate safety margins (sometimes called hardness design margins) into the design to eliminate/minimize hardness critical items should be superior investment strategy. The relatively small nonrecurring cost increases to achieve adequate safety margins should result in significant decreases in future recurring costs from reduced piecepart qualification, hardness assurance, and hardness maintenance programs.

2.4 Critical to the above approach is the early development of detailed guidance to design engineers. Electronic pieceparts susceptibility to nuclear environments must be characterized and the associated data made available to the designer. Since susceptibility is circuit as well as part dependent, hardness design techniques must also be developed and publicized. In many cases, the standard library of circuit designs used by designers, often company approved, must be modified. "Off-the-shelf", canned circuit designs may not provide the required hardness and/or reliability at the circuit level. Extensive renovation of the reference library of circuit designs may be necessary, and if necessary, priority attention must be paid this task. If the basic circuits in a sophisticated subsystem cannot meet their hardness/reliability allocation, the overall subsystem will have problems. For this reason, few existing off-the-shelf subsystems (which were not optimally designed) generally are compatible with the program specification and/or statement of work requirements. Such "off-the-shelf" systems, if used, must be treated as Contractor Furnished Equipment (CFE) subject to the same hardening and reliability requirements as new-design equipment. Subcontractors providing this equipment must be directed, guided and supported in their redesign to ensure compatibility of design approachs, approved parts listings, safety margins, reliability allocations, Hardness assurance design documentation (HADD) inputs, and hardness assurance/hardness maintenance (HA/HM) planning throughout the program. The prime contractor is responsible for compliance with the specification, for the generation of required documentation, and for compliance with the requirements of this statement of work not only for new design equipment, but for all mission critical equipment.

2.5 Included in the initial guidance to design engineers will be specific guidance for the safety margin analyses and formats for the documentation of the analyses for later collation and inclusion in the hardness assurance design documentation. The contractor shall also consider future assurance/maintenance tasks and utilize hardness designs which are easy and simple to verify by ordinary production workers and organizational maintenance personnel. For example, in a good design, LRU EMP shielding integrity may be assured by visual inspection. If all the scews/rivets are present and tight - LRU shielding is adequate. Where feasible, the contractor shall develop engineering-like requirements of an unclassified nature for their designers and for subcontractors. For example, an LRU not in a shielded area must have a case capable of carrying the specified currents without resulting in malfunctions of enclosed components. The design requirements may call for metal construction of the case, specified overlap and screw/rivet patterns for case components, waveguide treatment of drainage/ventilation holes, etc.

2.6 A key aspect of the hardening approach is the definition of hardness critical items (HCIs). These items will be the subject of tight (costly) controls throughout the operational life of the system. In this program all elements of mission critical subsystems will be designated either as hardnees critical or non hardness critical. For electronic pieceparts, hardness criticality is measured via hardness critical categories, i.e hardness critical category 1 (HCC1), hardness critical category 2, (HCC2), or non hardness critical (NHC). HCC1 parts are those pieceparts which must be treated on an exceptional basis because 1) their safety margins are

inadequate to insure long-term hardness unless special procurement controls are developed and utilized (HCC1M); 2) the parts are hardness dedicated, i.e. they are contained in the design exclusively for hardness (HCC1H). Examples of HCC1H parts may be gamma dose rate detectors which trigger circumvention, or zener diodes used to propect susceptible interface pieceparts from transient voltages induced by incident electromagnetic pulses; 3) they are nonstandard (HCC1S). These pieceparts are unique parts not procured subject to requirements of pertinent military standards (thus potentially subject to extreme variations in their response to nuclear environments). Except for special cases requiring detailed justification and prior Air Force approval HCC1S parts will not be used. If used, they will be treated as HCC1M parts, regardless of their safety margins. HCC2 parts are those with safety margins sufficient to insure long-term hardness with routine precaution. Non hardness critical parts are those which can not degrade hardness below criteria levels. For example, a wire-wound resistor is generically non hardness critical to blast, thermal, and total gamma dose environments. Each of the above categories is treated differently with the HCC1M category having the most stingent requirements. Note that a part cannot be both HCC1M and HCC1H. HCCIM categorization has priority. For example, if a zener diode is hardness dedicated, but if its own safety margin is small, it will be designated as HCC1M, if its safety margin is large, it is HCC1H.

2.7 The contractor should develop his own safety margins where practical and time permits. Design support nuclear environmental testing will be conducted to generate response data. These data and/or existing reliable data will be used to characterize the response of each part type to the nuclear environment of interest. These distributions may be used to define hardness critical categories: Otherwise the following table will be used to define the hardness critical categories.

Hardness Critical Category

Definition

Electronic Pieceparts

Nuclear Environment Category	HCCIM	HCC2	NHC
Nuclear Radiation			
Neutron Fluence	$SM<10$	$10<SM<100$	$SM>100$
Gamma Dose Rate	$SM<10$	$10\leq SM<100$	$SM\geq 100$
Gamma Dose	$SM<5$	$5\leq SM<25$	$SM\leq 25$
EMP Interface Specification	$SM<10db$	$10db\leq SM<30db$	$SM\geq 30db$

All Other System Elements

Nuclear Environment Category	Hardness Critical	Non Hardness Critical
Blast (Gust Overpressure)	Design Driven by Blast	Design <u>not</u> driven by Blast
Thermal (including Flash Environment)	Design Driven By Thermal	Design <u>not</u> driven by Thermal
Electromagnetic Pulse (Shielding)	Integral Part of System Shielding Effectiveness	<u>Not</u> required for EMP Attenuation
Nuclear Radiation	Design Driven by Nuclear Radiation	Design <u>not</u> driven by Nuclear Radiation

Contractor derived categories must be reviewed and approved by the Air Force prior to their use.

2.8 Each category is treated differently in the HADD documentation and in subsequent Hardness Assurance/Maintenance Programs. References 1 and 2 are to be used to define the different treatments. Of course along with such categorization must be the establishment of a strong and effective Configuration, Parts and Quality Control Programs applicable to all system elements/procedures. Change of any part of the system could result in massive changes in hardness criticality of numerous system elements/processes. Therefore all changes must be closely monitored for such adverse impacts.

2.9 The contractor shall design all mission critical system elements to minimize life cycle costs. As a design goal, the contractor shall strive to design each system element to be non hardness critical. If this is not possible because of adverse weight, performance, cost, and/or schedule impacts, or because of technology limitations, a firmer secondary goal for electronic pieceparts is the achievement of HCC2 status, if necessary, via use of protective HCC1H elements. Such HCC1H elements will be fail-safe, i.e. their failure causes detectable subsystem malfunction; or self-test or periodic field-level bench test will be incorporated. The HCC1M category is reserved for those few cases where it can be demonstrated that the above goals are technically impossible or cost prohibitive (nonrecurring costs are greater than recurring costs). For these situations, the contractor shall fully document his attempts to achieve the goal, and/or the cost trade study. This documentation will be reviewed and approved by the Air Force and will be incorporated into the hardness assurance design documentation along with the normal safety margin analysis.

2.10 The incorporation of adequate safety margins into system electronic equipment results in another bonus feature, simplified verification. In the majority of cases, verification of design hardness will be based on the analyses used to determine safety margins. Actual nuclear radiation tests of LRU level equipment would only be needed for a very few cases. (An exception may be testing of a computer protected via a circumvention scheme.) Neutron fluence tests, in particular, are to be minimized because of the destructive nature of the tests. Current injection tests of LRUs will also be minimized. Only if there are HCC1M parts in one or more interface circuits should such tests be conducted. The majority of the testing will be at the component/piecepart level.

2.11 Probably the one most important part of the Life Cycle Nuclear Survivability Program is documentation. Even a superior hardness design can be degraded rapidly during production or deployment unless preventative measures are taken. Such measures are highly dependent upon precise knowledge of the design, design elements, design technique, rationale for the technique, specific safety margins, etc. The amount of documentation required is massive and early planning is mandatory for its development, and acquisition; its content, formal storage, updating, security and accessibility; and its readibility and useability to future hardness assurance/maintenance personnel.

2.12 The name HADD (hardness assurance design documentation) has been bestowed upon this library of data and references 1 and 2 will be used by the contractor to guide his HADD efforts. A complete HADD is essential for hardness assurance and hardness maintenance, and it must be developed during full scale development. In fact, an extensive HADD development program, commencing immediately after contract award is necessary to insure a timely, cost-effective effort. After the Critical Design Review, the HADD should reflect the current system design configuration, as well as numerous other items required by the above references.

2.13 The specified reliability for the strategic mission length must be achieveable after system exposure to the specified nuclear environments. The EMP, blast, thermal, and gamma total dose exposures will be assumed to be at take off and the neutron fluence and gamma dose rate exposure will be taken to be at start of penetration. Close initial coordination between nuclear hardness and reliability engineers is essential to the satisfaction of this objective. Results from such coordination will be incorporated into the published design guidance. Close coordination between maintainability and nuclear hardness engineers is also necessary to insure satisfaction of potentially conflicting requirements. For example, EMP shielding effectiveness requirements tend to force designers to securely fastened, metallic construction. Accessibility requirements favor "quick disconnects" and lightweight construction. Close coordination is essential for the satisfaction of both requirements.

2.14 The contractor is encouraged to use the information storage, retrival, and updating capabilities inherent to the HADD for other significant program documents, e.g., ILS Reliability and Maintainability and Safety Programs. One central library facility would serve the entire program, which should reduce costly duplication of effort.

3.0 Specific Contractor Tasks

The contractor shall be guided by the philosophy and general consideration expressed in the previous section during the accomplishment of the following specific tasks.

3.1 The Contractor shall design the system to withstand exposure to the specified nuclear environments without loss of mission completion capability. As a design goal, the Contractor shall eliminate all HCClM pieceparts, and all hardness critical elements from the system. If this goal is not achieveable because of state-of-the art limitations or because cost (i.e. the nonrecurring design cost is greater than subsequent recurring costs) upon Air Force approval substantiating documentation will be prepared and incorporated into the HADD.

3.2 Design Support. Design support consists of all those actions required to guide, direct and support contractor and subcontractor design engineers in the accomplishment of maintainable hardness design at minimum life cycle costs.

3.2.1 Mission Critical Equipment Analysis. Because only mission critical equipment/components are required for strategic mission completion, only these equipment/components must be hardened. The contractor shall develop a list of such equipment/components for Air Force approval. This list will be maintained current at all times. The Contractor shall treat all mission critical equipment/components as Contractor Furnished Equipment (CFE) subject to the same control, design approach, safety margin, and philosophy.

3.2.2 Design Support Testing. The Contractor shall conduct design support testing as necessary to support the design and effort. Available data, if current and reliable, may be used to minimize the test program. Resulting nuclear environmental response data will be used to define hardness critical categories, to develop approved parts lists, and to support the development of parts specifications.

3.2.3 Design Guidelines. The Contractor shall prepare, document, and distribute design guidelines for electromagnetic effects (EMP, EMI, and lightning), and nuclear radiation (neutron fluence, gamma dose rate, and gamma total dose). The guidelines shall incorporate the latest state-of-the-art in design hardening techniques and shall be widely distributed to ensure contractor and subcontractor designers are using a uniform approach based on the latest and best information available. The guidelines will specifically address the concept of safety margin, and contain the design goals. They must also contain specific guidance/examples demonstrating combined circuit design/piecepart selection techniques which result in acceptable safety margins. The guidelines will also contain specific examples of safety margin analyses in the format for HADD incorporation along with firm requirements to the designers to document design techniques, rationale and other information necessary to support the construction of the HADD. Briefings and/or tutorials will also be conducted as required to acquaint designers and management personnel with the fundamentals of nuclear hardening and the impacts of the hardening effort on standard program functions. The guidelines will also address those design aspects of reliability, maintainability, safety, and other disciplines whose cooperation is mandatory for simultaneous satisfaction of all program design objectives. Blast and thermal environments will also be addressed, but since applicability of such guidelines will probably be more limited, separate documentation may be more cost effective.

3.2.4 Design Handbooks. The Contractor shall evaluate design handbooks used by both resident and subcontractor design personnel. If the handbook designs are not compatible with system requirements allocated down to the design level of interest, then such designs will be reaccomplished and the revised handbook provided to design personnel. Reliability, maintainability as well as hardness and operational requirements must all be simultaneously satisfied.

3.3 Blast and Thermal Design and Verification. The Contractor shall develop and implement a program to insure that the blast and thermal criteria are satisfied by the system design. Necessary development testing and analysis will be conducted and used both to support the design effort and system design verification. System level testing is not required. Computer aided analysis will be the primary method of verifying the design and providing data to support the generation of vulnerability envelopes.

3.4 Electromagnetic Pulse Design and Verification. The Contractor shall develop and implement a program to insure that the system and subsystem EMP requirements are satisfied. The Contractor shall conduct an analysis to determine the local EMP induced environments for each deliberate antenna, and for significant ports of entry. The results will establish/verify the requirements for each specific antenna and connecting electronics. For subsystem designs, a design goal will be the lack of HCC1M pieceparts. Exceptions will be documented. Emphasis will be placed on LRU case design, internal wiring and circuit board layouts to minimize coupling to buried circuits. Random analysis of typical buried circuits will be conducted on a small sample basis to provide confidence in the design. Subsystem design verification shall be by analysis and where there are HCC1M parts at the interface, by testing. Where necessary, methods will be developed to verify EMP shielding integrity of component elements, i.e. joints, door seals, etc. However, it will be a design goal to obtain acceptable shielding integrity via visual inspection, or other simple technique. Such designs greatly simply subsequent hardness assurance/hardness maintenance efforts. A system level EMP test of a fully equipped aircraft will be conducted using the USAF Trestle facility at Kirland AFB, New Mexico. Test plans will be prepared to cover all phases of the test. Pre-analysis will be accomplished and included in the test plan. Data reduction and post-test analysis will be accomplished and included in the test report. The system will be tested in various modes of degraded shielding, and critical interior points monitored. Such data will be used to sup ːt the hardness maintenance/hardness surveillance (HM/HS) Program, and t verify the pin specification adequacy for an aged system. The test report will also include a complete description of the test, the conduct of the test, test results and recommendations.

3.5 Nuclear Radiation Hardening Design Verification. The Contractor shall establish and implement a program resulting in minimum-cost nuclear radiation hardness over the system life. Safety margins sufficient to minimize life cycle control and monitoring are crucial to this objective. As a design goal, the contractor shall eliminate HCC1M parts from the design. Exceptions will be documented. The breakpoint between HCC1M and HCC2 are as shown in para 2.7 unless contractor derived breakpoints are developed. Design verification shall be by analysis, supported by piecepart tests and in some cases by testing of circumvention/clamp circuit. No LRU tests are required. An analysis will be conducted on semiconductor pieceparts and circuits to determine the safety margins. Piecepart and circuit margins and parts categorization will be determined from the analysis. If the analysis indicates that the part fails to meet the requirements, part substitution,

circuit redesign and circumvention will be considered. Deviations from the defined Hardness Critical Category (HCC) breakpoints for selected pieceparts shall be substantiated. For example, test data on a specific piecepart may show latch up and photo current caused burnout from gamma rate will always occur above the specification level but below the standard HCC2 breakpoint. For this case, designating the piecepart as HCC2 would not reduce hardness confidence, but would reduce production and maintenance cost.

3.6 Hardness Assurance. Although the hardness assurance program does not formally begin until after production decision, considerable prerequisite efforts are required during full scale development. The first effort is the development of an overall plan of attack which defines the tasks required during full scale development to support minimum cost hardness assurance/ maintenance. In addition to the previously noted design guidelines, the contractor shall develop formats and guidelines for initiation, development, and maintenance of the Hardness Assurance Design Documentation (HADD). The HADD in its entirety is a deliverable item. Contractor developed formats will be used to guide the development. Normally the HADD would be transitioned to the responsible Air Force agency after the full scale development program. In the event of program cancellation, the Contractor shall complete the HADD as much as possible and deliver it to the Air Force. In addition, production procedures will be developed to provide strict control over system configuration. All changes must be monitored and controlled to prevent deterioration of the hardened design. Existing military standards (amended as required) shall be the basis for such change control, parts control, and manufacturing/inspection procedure control. Parts specifications will be developed for hardness critical design elements.

3.7 Hardness Mainenance and Hardness Surveillance (HM/HS). A hardness maintenance and hardness surveillance plan will be developed to ensure that the production system remains hard during its life cycle. The HM/HS plan will be written incorporating HM/HS procedures developed during full scale development and production. HM/HS test equipment, if required, will be designed and fabricated under separately funded procurement. The Contractor shall incorporate into the HM/HS program all "hardness" related requirements (i.e., nuclear, RCS, lightning, etc.) which will mandate special maintenance/surveillance procedures/attention upon deployment.

3.8 Inherent Laser Hardness. The inherent laser hardness of the system will be assessed using results of laser tests of selected surface materials and coatings, and structural sections.

3.9 Crew Protection Analysis. Crew protection requirements will be analyzed for the nuclear environments to be encountered, including passage through a radioactive cloud. These environments will include radioactive dust ingested through the ECS inlets, thermal (flash blindness and skin burns), and nuclear radiation. Protection requirements will be identified along with potential benefits to be gained from implementation.

3.10 On-Board EMP Hardness Monitor. An on-board means of verifying system hardness to EMP is highly desirable. In particular, prior to entry onto strategic alert the system's capability to protect its electronic subsystems from incident EMP environments should be gaged, i.e., the system shielding effectiveness (S.E.) or equivalent, should be acceptable. The contractor shall investigate the feasibility and practicality of providing this built in test (BIT) capability. The best technique(s) will be presented to the A.F. for evaluation and approval.

3.11 Software. Software use, requirements and application to hardening will be examined and implemented as required. Applications will include reset for upset and commands for possible data storage and retrieval for circumvention. Hardness critical software will be identified and controlled.

3.12. Parts Criticality Integration. The Contractor shall review other aspects of the program and evaluate the feasibility and practicality of integrating "critical" parts control into the normal hardness critical control effort. The concepts, techniques, and methodology of hardness critical item (HCI) control are well established and could be extended to "reliability" critical items, "survivability" critical items, etc. Any special controls, assurance/maintenance requirements, parts specifications, etc. could be integrated into the Hardness Acsurance/Maintenance Program.

3.13. Survivability/Vulnerability (S/V) Analysis. An S/V analysis will be made for the SIOP mission profile and required nuclear weapon yields for the various mission phases. These phases include base escape, enroute (with possible aerial refueling) , penetration. The S/V analysis will consider the blast (overpressure ano .ıst), thermal, and nuclear radiation environments. The analysis will include, but not be limited to, vulnerability envelopes for free-field environments and responses to the environments as a function of aspect angle. Only the EMP high altitude criteria will be addressed.

3.14. Coordination and Monitoring of Equipment Suppliers. The Contractor will direct, coordinate, and monitor suppliers of contractor furnished equipment (CFE) for nuclear hardness assurance, nuclear hardness design, analysis, and/or testing throughout the program. The Contractor will provide design guidelines and other guidance to suppliers to insure the implementation of ‹ ‵ıclear Hardening Program compatible with the intent and requirements of this SOW.

3.15 Drawing Annotations. Individual nuclear Hardness Critical Items (HCIs) shall be identified on the drawing, on the parts list, and/or on the list materials. Nuclear Hardness Critical Items are defined as any items at any assembly level which are mission critical and which require special procurement controls/unique specification requirements to prevent degrading of system hardness. (Hardness criticality is defined in Table I. For electronic pieceparts, only HCC1 parts are to be considered HCI's). Hardness Critical Processes (HCPs) must be identified in drawings and drawing notes.

Nuclear Hardness Critical Processes are processes, specifications, and/or procedures which are hardness critical, (i.e. required to assure hardness is achieved during production and/or to maintain hardness during operational deployment) and which could degrade nuclear hardness if they change.

Hardness Critical Items are to be marked: HCI

Hardness Critical Processes are to be marked: HCP

Drawings that contain HCIs or HCPs shall have the following statement on the face of the drawing:

> "This drawing contains Hardness Critical Items or Hardness Critical Processes. Refer to the appropriate section of the (Weapon System Name) Hardness Assurance Design Documentation for more information."

In addition all drawings of all mission critical design elements and higher level assemblies shall have the following statement on the face of each draw drawing:

> "This drawing contains Mission Critical Items of the (Weapon System Name). All changes must be evaluated for impacts to system hardness."

3.16 Visibility. Air Force visibility into the Nuclear Hardness Program shall be via informal technical interchanges, formal design reviews and periodic Nuclear Hardness Program Status reports. Informal interchanges may be scheduled at the request of either the Contractor or the Air Force at any time, otherwise the Contractor shall plan on hosting such interchanges on a quarterly basis. Such meetings shall be the major vehicle for timely Air Force review and approval of on-going efforts and to resolve any Air Force or contractor concerns. The Contractor shall record minutes of each meeting for permanent record. The Nuclear Program Status Report will be quarterly reports delivered to the Air Force not less than 15 days prior to the technical interchange. The Status Reports will consist of loose-leaf pages to allow for updating via page replacement interchanges. Material in original reports need not be duplicated in subsequent reports. The initial report will also contain the outline of the Nuclear Program Management Structure, its relative position in the overall Program and the relationship with other technical and managerial program agencies. An overall Nuclear Hardness program Task/Milestone chart will be included and updated in subsequent reports. In addition, each report shall contain "executive summary" detail of the status of each of the specific tasks required by this Appendix with reference to the complete documentation available in the HADD. Updates of previously reported areas will also be included.

4.0 REFERENCES

1. Patrick, R. and J. Ferry, "Nuclear Hardness Assurance Guidelines for Systems with Moderate Requirements", AFWL-TR-147, Air Force Weapons Laboratory, Kirtland AFB, NM, September 1976.

2. Patrick, R. and J. Ferry, "Nuclear Hardness Assurance for Aeronautical Systems", Paper 801227, Aerospace Congress & Exposition, Los Angeles Convention Center, October 1981. (Order from Society of Aerospace Engineers, Inc. 400 Commonwealth Drive, Warrendal, Penn. 15096.)

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